Article (refereed) - postprint

Brownlie, Will J.; Howard, Clare M.; Pasda, Gregor; Nave, Barbara; Zerulla, Wolfram; Sutton, Mark A.. 2015. **Developing a global perspective on improving agricultural nitrogen use.** *Environmental Development*, 15. 145-151. https://doi.org/10.1016/j.envdev.2015.05.002

Developing a global perspective on improving agricultural nitrogen use.

Experiences from the Second BASF Fireside Chat Nitrogen (26-27th March 2015, Albersweiler, Germany)

Will J Brownlie[1,a], Clare M. Howard[1], Gregor Pasda[2], Barbara Nave[2], Wolfram Zerulla[2], Mark A. Sutton[1]

[1] NERC Centre for Ecology & Hydrology, Edinburgh Research Station, Bush Estate, Penicuik, Scotland, EH26 OQB, UK.
[2] BASF SE, G-APG/RC - LI470, 67117 Limburgerhof, Germany.

Abstract

Nitrogen (N) fertilisers help ensure food security for many regions in the world, but excess or inappropriate use can have serious impacts on both human and environmental health (e.g. threatening air, soil, and water quality, reducing biodiversity and disrupting of greenhouse gas balance). While losses are exacerbated by the decoupling of animal and crop production systems, there are many opportunities to reduce N pollution and increase productivity simultaneously. On the 26th and 27th of March 2015, delegates from diverse backgrounds met at the Second BASF Fireside Chat Nitrogen to discuss these issues and explore possible solutions. Stakeholders from some regions emphasized the desire to avoid simplistic regulations, encouraging the empowerment of farmers to develop their own solutions. Other regions highlighted the need for more effective government intervention. This applied both for adoption of emission mitigation methods in regions of excess, as well as for good governance and infrastructure to improve fertilizer supply in regions of too little. A core message was that, although strategies to increase N use efficiency vary between global regions, there are substantial common themes, the shared development of which could greatly strengthen global action.

These challenges are now being taken up by the International Nitrogen Initiative and the United Nations Environment Programme. With financial support from the Global Environment Facility, they are working towards an International Nitrogen Management System (INMS) to provide coordinated scientific support for international N policy-making.

Introduction

BASF SE recently cooperated with the Centre of Ecology & Hydrology to organise the second BASF Fireside Chat on Nitrogen in Albersweiler, Germany.

Sixty international delegates, from a diverse range of backgrounds, including agriculture, (farmers), science, industry and policy, were invited to take a closer look at the issues surrounding the use of nitrogen (N) in agriculture. A series of talks from representatives of North America, South America, Australia, South and East Asia, Africa and Europe were given on the first day. A truly global representation of the success stories, issues and potential

[a] Correspondence: Will Brownlie, Centre for Ecology and Hydrology, Edinburgh Research Station, Penicuik, Midlothian, Scotland, UK, EH26 OQB. Email: wilown@ceh.ac.uk, Phone: (+44) 0131 445 4343

barriers regarding better N management from the perspectives of farmers, scientists, policy makers and industry were shared. On the second day, delegates formed working groups to discuss potential measures to improve N management in the different global regions, be it at the farming, research, or political level.

The workshop was co-designed by BASF SE and the International Nitrogen Initiative (INI), a global action jointly under the Scientific Committee on Problems of the Environment (SCOPE) and the International Geosphere Biosphere Programme (IGBP) (INI, 2015), and which is currently in transition towards the "Future Earth" global sustainability research network. This co-design allowed engagement with a wide range of stakeholders, which is especially relevant as INI prepares to start a new research effort on the global N cycle, 'Towards the establishment of an International Nitrogen Management System' ('Towards INMS').

This major global project is being prepared through 2015 under the lead of INI and the United Nations Environment Programme (UNEP), with financial support from the Global Environment Facility (GEF). In GEF terms, UNEP is the 'Implementing Agency' and INI the 'Executing Agency', with the latter represented by the UK Natural Environment Research Council.

INI has long recognized that there is no global process to coordinate scientific evidence in support of N policy making (Sutton et al., 2013). The preparations for 'Towards INMS' are therefore now addressing this gap, at the same time prompting discussion with key international policy frameworks. While the goals of INMS represent all sources, benefits and threats of N, agriculture is clearly recognized as the largest source of reactive N compounds (N_r) in the environment (Billen et al., 2013; Fowler et al. 2013). The 2nd BASF Fireside Chat on Nitrogen was therefore an ideal opportunity to engage with agricultural N stakeholders from around the world, to hear their views and to reflect on the different challenges faced.

Here we summarize the thoughts and ideas which emerged during the workshop. Further information is provided in a posters document which summarizes the report from each working group (INMS, 2015a). The outcomes from the workshop are being used directly to inform development of 'Towards INMS', including at subsequent workshop in Lisbon (Towards INMS Plenary) and Edinburgh (INMS pump priming: global nitrogen integrated assessment modelling) (INMS, 2015b, 2015c).

As will be seen from what follows, although the issues surrounding N management in agriculture vary between regions, a core message emerged that there are substantial common themes globally. This picture of unity in diversity is illustrated in Figure 1. The next section summarizes emerging messages from the different regional discussions, followed by views that were shared globally.

Regional issues and solutions

North America

Water degradation due to N losses from agriculture was identified as a key driver to improve N management in the USA. The discussion suggested that current change in agricultural practice is led by farmers, with regulation and policy playing only a minor role. It was proposed by that nutrient use efficiency will be best achieved through co-operation and

engagement with farmers. It was felt that the fertiliser industry, food industry and scientists should take an active role together with farmers in this.

During the workshop Jean Payne of the Illinois Fertiliser & Chemical Association (www.ifca.com) explained that engaging with local famers and advisors had yielded a decrease in pollution in Illinois, avoiding the immediate need for policy restrictions. They also adopted a pro-active communication strategy with environmental bodies on future pollution episodes, which has increased trust between the organisations involved especially by addressing misconceptions.

South America

Increasing efficient fertiliser use in sugar cane and cattle production, and reducing the burning of forests were considered key opportunities to better manage N in South America. Development of technologies such as enhanced efficiency fertilisers (EEF) were considered to show great promise, but fertilizers and application methods need to be appropriate and realistic for local farmers to use (e.g. fertiliser application by aeroplane).

Improvements in infrastructure to support sufficient fertiliser availability to small landholders, and an increase in the recycling of nutrient from wastes and stabilizing consumption of animal products will further improve regional N management (Sutton et al. 2013).

Australia

Australia has a huge land mass with a relatively low population. Little environmental legislation and a lack of farming subsides were considered to have hindered farmers in adopting better N management. However, an encouraging $2 billion investment to reduce N delivery to the Great Barrier Reef highlights the growing importance placed on improving N management. In addition, the National Agricultural Nitrous Oxide Research Program aims to show the benefits of using inhibitors (urease and nitrification inhibitors) to reduce N losses, especially the nitrous oxide emissions.

Fertiliser is considered to be commonly overused in dairy farming, whilst in arable farming soil N mining occurs and organic matter increase in dry land is needed. In cattle 65% of dietary N is estimated to be lost as NH_3 (70 kg N $head^{-1}$ yr^{-1}) (Flesch et al. 2007). Addition of brown coal to the surface of cattle feedlots are considered to be promising approaches to reduce NH_3 release, while EEF offer further opportunities to improve N use efficiency (NUE). However, controlled release coatings for fertilisers remain prohibitively expensive for many farmers.

It was considered that there is also a need to develop a benchmark N footprint to support legislation to reward good behaviour, much like the Carbon Farming Initiative (CFI) for farmers that adopt better carbon management (Australian Department of Climate Change and Energy Efficiency. 2011).

South Asia

At the other end of the scale to Australia, India accounts for 16.2% of the world population, living within 2.4% of the land area of the planet. Farms are generally small plots manually farmed with low technology machinery and this should be kept in mind when developing measures to improve NUE.

Currently in much of this region, N losses from rice crops are estimated to be greater than N used by rice crops (Fageria et al. 2015). Urea Super Granules added to fertilisers and precision fertiliser sowing, combined with use of residue mulch to reduce NH_3 volatilisation, all provide opportunities to improve NUE. Reduction of government subsidies on N fertilizers is one way to foster change. Use of the postal service to deliver fertilizer to areas where infrastructure prohibits their availability was considered as a strategy that should be further investigated.

East Asia

Policies to boost food production in China provided subsides to encourage N fertiliser use and resulted in an estimated decrease in NUE by 50% between 1950-2000 (Smith and Siciliano 2015). Although this policy was successful in terms of improving food security, it resulted in an almost endemic over-use of N fertiliser, pesticides and fungicides in the region. Such changes have contributed to food becoming increasingly expensive (so much so that China now imports maize from the USA as it is up to 30% cheaper than Chinese maize) and caused widespread eutrophication of freshwaters (Lu et al. 2015).

It was considered that a major change to agriculture in this region would occur in 2020 if farmer's subsidies are discontinued. Apparently there are proposals to consider this option, and future management options should be developed with this in mind.

Africa

In much of Africa there is in not enough fertiliser available to produce sufficient food (Hernandez and Torero 2011) and too little crop growth to protect soils from erosion. At the same time, there is inadequate sewerage to treat wastewater and stop nutrient delivery into limited freshwater reserves.

The major barriers to change were considered to be infrastructure and finance. Better finance and an enabling environment in terms of policies and administrative costs are required in order to improve transport and provide adequate storage for fertilisers. Furthermore it was considered that the scientific community needs to be better supported if the contributions of N sources are to be better understood.

A major goal for this region is to support sustainable growth and deliver aspirational goals for the region for food security, nutrition, income, and health. Job creation and circular economy models were considered by the group to be a better way of promoting change in a region where following policy is 'optional' and often bypassed by industry.

Although for farmers to adopt better N management, many need access to finance and effective extension services (i.e. knowledge from governments and agricultural NGOs through application of information and communication technologies) as well as access to inputs' and outputs' markets (Mutambara et al. 2014).

Europe

It was noted that in the EU27 in 2008, the cost of the impacts of agricultural N use outweighed the benefits. Nitrogen pollution costs for human health, ecosystem and climate impacts were noted to have been estimated at a net of 35-230 billion euro yr^{-1}, whilst direct benefits to agriculture through greater crop growth is estimated at 20-80 billion euro yr^{-1} (Sutton et al. 2011; Van Grinsven et al. 2013). On the other hand, it was also recognized that agricultural production also provided many down-stream benefits, which had not been fully valued (Erisman et al. 2008).

It was highlighted by delegates that whilst the influence of governments in the EU is decreasing, that of industry (suppliers, food and feed industry) is increasing. Similarly farmers in the EU are showing some initial signs of taking initiatives for more self-governance.

The group considered that increasing public awareness of the indirect effects of food and food production on health to the consumer would support demand for an increase in the sustainable farming concept and the products they produce. However, the food industry would need to play a key role in this. Furthermore creating a legislative framework for circular economies and developing support for N waste recycling technologies and reduction of N losses will support policies designed to improve N management.

Issues shared between regions, disciplines and stakeholders

The 2nd BASF Fireside Chat Nitrogen highlighted that integrated strategies to communicate best practices are required in all regions. The benefits of improving NUE need to be better quantified and need to be translated into data and metrics that are easy to communicate to stakeholders.

Farmer-to-farmer dialogue was acknowledged as a powerful platform for knowledge exchange, especially by the farmes themselves, emphasising the importance of supporting 'farming champions' to guide change.

It was also highlighted that the need for better N use offered a great opportunity for business development. This applied whether tailoring the design of fertilisers, using fertiliser additives (e.g. urease or nitrification inhibitors), precision farming, or the use of sensors and visual assessments using unmanned aerial vehicles, plant breeding and genetically modified organisms. All of these could contribute to Green Economy development, though different regions may vary in their emphasis of priorities.

It was clear from the workshop that there is no single solution to the global N challenge. We need cooperation. Stakeholders differ from country to country, and engagement should be tuned accordingly. There is also a need to engage more with food and feed industries. This would allow the development of more effective and relevant measures or policies and increase public awareness.

The experiences shared within this meeting were clear evidence of the benefit to be found by bringing different disciplines and stakeholders together to address the N challenge.

Acknowledgements

On behalf of both INI and BASF SE, the authors gratefully acknowledge support from BASF SE for financing the 2nd Fireside Chat and the support from the Global Environment Facility (GEF) through the United Nations Environment Programme (UNEP) for preparation of the 'Towards INMS' project. Co-financing was provided through the INMS pump-priming (INMSpp) project through the UK Natural Environment Research Council "International Opportunities Fund", the EU ÉCLAIRE project, and through the INI "Nitrogen in Future Earth" cluster activity, supported by the Future Earth programme. We are grateful to all who participated in the BASF fireside chat on Nitrogen, and those who acted as rapporteurs for the regional working groups: (for full list see: INMS, 2015a)

References

Billen G., Garnier J., Lassaletta L. 2013. The nitrogen cascade from agricultural soils to the sea: Modelling N transfers at regional watershed and global scales. Philosophical Transactions of the Royal Society Ser. B. 368 (1621), 1-9.

Australian Department of Climate Change and Energy Efficiency. 2011. The Carbon Farming Initiative Handbook Version 1.0. (http://www.climatechange.gov.au/sites/climatechange/files/files/reducing-carbon/CFI-Handbook-20120403-PDF.pdf.)

Erisman, J. W., Sutton, M. A., Galloway, J. N., Kilmont, Z., Winiwarter, W. 2008. How a century of ammonia synthesis changed the world. Nature GeoScience, 1, 636–639.

Fageria, N.K., Baligar, V.C., Heinemann, A.B., Carvalho, M.C.S., 2015. Nitrogen Uptkae and Use Efficinecy in Rice. Nutrient Use Efficiency: From Basics to Advances. Springer India. pp 285-296.

Flesch, T. K., Wilson, J. D., Harper, L. A., Todd, R. W., & Cole, N. A. 2007. Determining ammonia emissions from a cattle feedlot with an inverse dispersion technique. Agric. For. Meteorol., 144, 139–155.

Fowler D., Coyle M., Skiba U., Sutton M., Cape N., Reis S., Sheppard L., Jenkins A., Galloway J., Vitousek P., Leech L., Bouwman L., Butterbach-Bahl K., Dentener F., Stevenson D., Amann M. & Voss M. 2013. The Global Nitrogen Cycle in the 21st century. Philosophical Transactions of the Royal Society Ser. B. 368 (1621).

Hernandez, M.A., Torero, M. 2011. Market structure, consumption and trade patterns, and pricing behavior. International Food Policy Research Institute (IFPRI) Discussion Paper 01058. IFPRI, Washington.

INI. 2015. www.initrogen.org

INMS. 2015a. Regional Posters Document on Agricultural Nitrogen Challenges. 2nd BASF Fireside Chat Nitrogen (Albersweiler, 27-28 March 2015). www.inms.international/documents.

INMS. 2015b. Agenda and background documents for the 'Towards INMS' Plenary Meeting (Lisbon, 27-28 April 2015). www.inms.international/inms-meeting-lisbon/inms-lisbon-background-documents.

INMS. 2015c. Agenda and background documents for the INMSpp workshop on global nitrogen integrated assessment modelling. www.inms.international/inmspp-and-tfiam-may-2015

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., Garnier, J. 2014. 50 Year Trends in Nitrogen Use Efficiency of World Cropping Systems: the Relationship Between Yield and Nitrogen Input To Cropland. Environmental Research Letters, 9 (10), 1-9

Lu, Y., Jenkins, A., Ferrier, R.C., Bailey, M., Gordon, I.J., Song, S., Huang, J., Jia, S., Zhang, F,. Liu, X., Feng, Z., Zhang, Z. (2015) Addressing China's grand challenge of achieving food security while ensuring environmental sustainability. Science Advances. 1(1). e1400039.

Mutambara, S., Mutambara, J., Darkoh, M. B. K. (2014). Towards sustainable stakeholder engagement in smallholder irrigation schemes in Zimbabwe. African Journal of Agricultural Research, 9 (50), 3587-3599.

Smith, L. E. D., Siciliano, G. 2015. A comprehensive review of constraints to improved management of fertilizers in China and mitigation of diffuse water pollution from agriculture. Agriculture, Ecosystems & Environment, xxx, xxx–xxx.

Sutton, M. A., Howard, C. M., Erisman, J. W., Billen, G., Bleeker, A., Grennfelt, P., et al. 2011. The European Nitrogen Assessment: Sources, Effects and Policy Perspectives. Cambridge Univeristy Press, Cambridge.

Sutton, M.A., Bleeker, A., Howard, C.M., Bekunda, M., Grizzetti, B., de Vries, W., van Grinsven, H.J.M., Abrol, Y.P., Adhya, T.K., Billen, G., Davidson, E.A, Datta, A., Diaz, R., Erisman, J.W., Liu, X.J., Oenema, O., Palm, C., Raghuram, N., Reis, S., Scholz, R.W., Sims, T., Westhoek, H., Zhang, F.S., Ayyappan, S., Bouwman, A.F., Bustamante, M., Fowler, D., Galloway, J.N., Gavito, M.E., Garnier, J., Greenwood, S., Hellums, D.T., Holland, M., Hoysall, C., Jaramillo, V.J., Klimont, Z., Ometto, J.P., Pathak, H., Plocq Fichelet, V., Powlson, D., Ramakrishna, K., Roy, A., Sanders, K., Sharma, C., Singh, B., Singh, U., Yan, X.Y., Zhang, Y., 2013. Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative114 (http://initrogen.org/index.phppublications/our-nutrient-world/.)

Van Grinsven, H. J. M., Holland, M., Jacobsen, B. H., Klimont, Z., Sutton, M. A., & Willems, W. J. 2013. Costs and Benefits of Nitrogen for Europe and Implications for Mitigation. Environmental Science and Technology, 47 (8). 3571–3579.

Figure 1. Nitrogen management in different global regions. Outer boxes detail region descriptions (% population of each region, % land area, typical farm size, agriculture type and level of technology used); mid-boxes detail nitrogen input ($kg^{-1}ha^{-1}yr^{-1}$), in terms of maximum protein yield of cropping systems (taken from Lassaletta et al. 2014); inner boxes give example solutions to better manage nitrogen in each region; the central box details solutions shared globally.